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(54) **Improved stabiliser for Biodegradable polyester processing**

(57) This invention relates to a stabilised biodegradable polyester composition, comprising a biodegradable polyester of lactic acid and/or glycolic acid, and a stabi-

liser which comprises (a) a phosphite- or phosphate-containing compound and/or a hindered phenolic compound, and (b) an acrylate.

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Description

[0001] Biodegradable polymers are finding increased use as an environmentally friendly option to non-degradable polymers such as PP or PS or PET in many applications. In the class of biodegradable polyesters, poly(lactic acid) or polylactide polymers, known hereafter as PLA, are of commercial interest. Poly(glycolic acid) and lactic acid/glycolic acid copolymers are also useful. However, PLA suffers from stability problems at the high temperatures used during production and processing. This can result in deficiencies of PLA polymer and products such as discolouration or molecular weight (mw) reduction or lowering of crystallinity levels.

[0002] Cargill Inc (WO 94/07949) have made an attempt to overcome the high temperature depolymerisation problems associated with PLA. This depolymerisation is cited in terms of lactide monomer regeneration and mw reduction. The use of antioxidants or water scavengers or mixtures of antioxidants and water scavengers for this purpose is disclosed. The range of antioxidants includes alkyl and aryl phosphites, phosphonites, hindered phenolic compounds, aromatic amines, thioethers, quinones and mixtures of these. However, Cargill only demonstrate the effects of each of these stabiliser types singly through the Examples quoted in WO 94/07949 and do not evaluate mixed antioxidant packages. The stabiliser addition could be either before or after PLA polymer production. Cargill failed to prevent discolouration of the PLA polymer through the use of antioxidants unless conversion of lactide to polymer was restricted to <85% and mw<40,000. This low mw and level of conversion to PLA is not sufficient to develop the full properties of PLA polymer. This requires the PLA mw to be >70,000 according to Cargill. In commercial grade PLA, where good and consistent levels of properties are necessary, Cargill failed to demonstrate an effective anti-yellowing stabiliser. The stabilisers used in WO 94/07949 generally lead to deterioration in the level of crystallinity in PLA polymers. This results in deleterious consequences for a semi-crystalline polymer such as PLA. We have demonstrated that these problems with crystallinity and yellowing exist for the single antioxidants cited by Cargill (see Comparative Examples 1-27).

[0003] This problem with molecular weight reduction is also highlighted by Neste OY (WO 95/18169). In this document, it is noted that conventional stabilisers which can be used with aromatic polyesters are not effective with lactic acid polymers. Neste OY made use of peroxides to limit PLA mw reduction during processing by extrusion. Peroxides are limited to use after PLA production and cannot be added to the PLA production process (see also Comparative Examples 26-27).

[0004] Shell (GB 1,161,932) disclose the use of amine-based stabilisers for reducing the thermo-oxidative decomposition of aliphatic polyesters, especially cyclic lactone derived polymers. The stabiliser can be used singly, or in combination with a wide range of other species. The stabiliser(s) can be added either to the lactone precursor or the polymer product as alternative routes for incorporation of the stabiliser(s) into the polymer. However, although the intrinsic viscosity of the polymer may be maintained by addition of stabiliser, it is clear that discolouration of PLA cannot be prevented by amine-based stabilisers (see Comparative Examples 21-23).

[0005] Thus, there exists a need for an improved stabiliser for use in PLA which prevents discolouration and maintains mw and crystalline melt temperature (T_m) of commercial-type PLA polymer. We have found that a mixture of stabilisers is required for this purpose.

[0006] We have provided a stabilising package for aliphatic polyesters, especially PLA polymers. The stabiliser package serves several purposes;

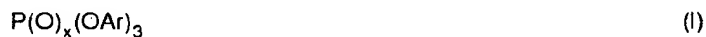
- prevents the discolouration or yellowing of the polymer during production and moulded articles manufactured from it
- prevents any reduction in T_m (often observed with standard stabilisers)
- limits the reduction in crystallinity of the polymer (observed with standard stabilisers).

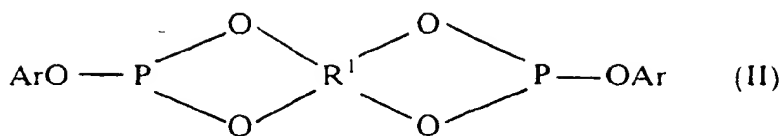
[0007] The present invention provides a stabilised biodegradable polyester composition, comprising a biodegradable polyester of lactic acid and/or glycolic acid, and a stabiliser which comprises (a) a phosphite- or phosphate-containing compound and/or a hindered phenolic compound, and (b) an acrylate.

[0008] The polyester is preferably obtained by polymerisation of lactide and/or glycolide.

[0009] The stabiliser preferably comprises a phosphite- or phosphate-containing compound and an acrylate, and more preferably comprises a phosphite- or phosphate-containing compound, a hindered phenolic compound and an acrylate.

[0010] The phosphite- or phosphate-containing compound is preferably of the general formula (I), (II) or (III):





in which

x is 0 or 1;

Ar each independently is an optionally substituted aromatic group; and

R¹ and R² are aliphatic or aromatic groups.

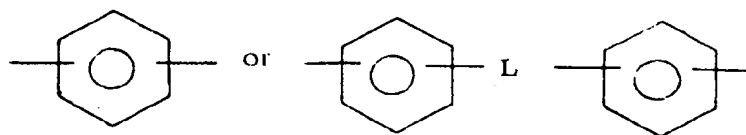
[0011] Ar is preferably phenyl or naphthyl, and is preferably substituted by C₁-C₁₀ alkyl or C₁-C₁₀ alkoxy.

[0012] R¹ is preferably a C₄-C₁₀ aliphatic hydrocarbon group (most preferably C(CH₂)₄) or an aromatic group of the formula:



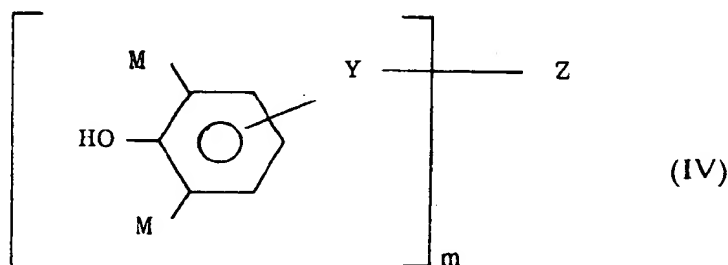
where L is a direct bond or a linking group such as S, SO, SO₂, CO, O or C₁-C₆ alkylene.

[0013] R² is preferably a C₁-C₁₀ aliphatic hydrocarbon group (most preferably an alkylene, alkyleneoxy or oxyalkyleneoxy group, where the alkylene moiety is optionally interrupted by one or more O atoms) or an aromatic group of the formula:



where L is as defined above.

[0014] The hindered phenolic compound is preferably of the general formula (IV):



where

M each independently is an aliphatic group;

Y is an aliphatic group;

m is an integer from 1 to 4; and

Z is an aliphatic or aromatic group or

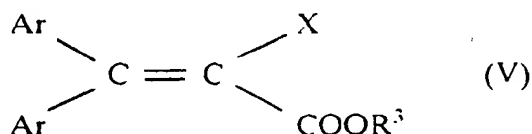
H if m is 1.

M is preferably C₁-C₁₀ alkyl or C₁-C₁₀ alkoxy.

Y is preferably C₁-C₁₀ alkylene or C₁-C₁₀ alkylencarboxy, where the alkylene moiety is optionally interrupted by one or more O atoms.

Z is preferably a C₁-C₂₀ aliphatic hydrocarbon group, or a 6-membered carbocyclic or heterocyclic aromatic ring.

[0015] The acrylate is preferably of the general formula (V):



where

Ar each independently is an optionally substituted aromatic group;

R³ is an aliphatic group; and

X is an electron-withdrawing group.

Ar is preferably phenyl or naphthyl, and may be substituted by C₁-C₁₀ alkyl or C₁-C₁₀ alkoxy.

R³ is preferably C₁-C₁₀ alkyl optionally interrupted by one or more O atoms.

X is preferably cyano or halogen.

[0016] The total content of stabiliser is preferably up to 2 wt%, more preferably from 0.1 to 0.5 wt%, of the weight of biodegradable polyester.

[0017] The invention also relates to use of a stabiliser composition comprising (a) a phosphite-containing compound and/or a hindered phenolic compound; and (b) an acrylate, for stabilising a biodegradable polyester of lactic acid and/or glycolic acid.

[0018] The invention further provides a process for preparing a stabilised polyester composition, which comprises polymerisation of lactide and/or glycolide in the presence of a stabiliser comprising (a) a phosphite-containing compound and/or a hindered phenolic compound, and (b) an acrylate.

[0019] The invention additionally provides a shaped product prepared from a stabilised biodegradable polyester composition as defined above.

[0020] The stabiliser package should be a combination of different chemical types taken from the list; phosphite or phosphate, hindered phenolic, acrylate. Multifunctional and closely related chemical types such as phosphonite and fluorophosphonite perform in a similar manner as simple phosphite, phenolic and acrylate compounds. Materials which are found to destroy the desired action and outcome of using our stabiliser package include aromatic amines, peroxides, organo-metallic complexes, thioethers or other organic sulphur compounds and are specifically excluded at addition levels of >0.5 wt%. The preferred combinations are a package including a compound from each of the phosphite or phosphate and phenolic and acrylate classes or a package including compounds from phosphite or phosphate and acrylate classes. Any member of these chemical classes may be used, but the preferred materials are alkyltriphenyl phosphites, alkylidiphenylphosphates, bis[alkylphenyl]pentaerythritol diphosphites (phosphite or phosphate class), alkyl-[di-*t*-butyl hydroxyphenyl]propionates, butylated hydroxytoluenes (hindered phenolic class), alkyl esters of 2-cyano-3,3-diphenylacrylic acid (acrylate class).

[0021] The combination of stabilisers can be present when the lactide monomer is converted to PLA without interfering with the polymerisation catalyst. The PLA polymer produced is of high mw (>150,000), high T_m (>170°C), high crystallinity levels (>40%) and very low colour (essentially colourless). This combination of PLA properties has never before been achieved together. The presence of the stabilisers in the "as produced" PLA also protects the PLA in any further fabrication steps and eliminates the need to compound the PLA further before moulding to final product form.

[0022] The following Examples illustrate the invention.

[0023] **Comparative Example 1-27.** Vial polymerisations of pure L-lactide were carried out at 180°C for 20 hours. The catalyst used was tin octoate at a concentration level of 50ppm with respect to the lactide monomer. All stabilisers

were added at 0.25 wt%. Analysis of mw, Tm, crystallinity level (%cr) and yellowness index (YI) of PLA product was carried out by standard methods and the results are given in Table 1. The method of analysis were:

mw - GPC (gel permeation chromatography)

Tm, crystallinity - DSC (differential scanning calorimetry)

YI - spectrometry. Product designations in Table 1 are tradenames or registered trademarks.

Table 1.

Example	Stabiliser	PLA mw	PLA Tm	%cr of PLA	PLA YI
1	None (control sample)	278,100	177	49	15
2	None (control sample)	256,900	178	47	15
3	None (control sample)	264,000	177	49	15
	<i>Phosphorus-based.</i>				
4	Irgafos 168	279,300	173	27	10
5	Santicizer 148	265,000	98	8	11
6	Triphenyl phosphite	292,300	159	21	13
7	Alkanox P24	312,500	175	26	13
8	Alkanox 240	235,700	169	32	12
9	Lowinox TNPP	210,200	167	32	12
10	Ethanox 398	66,800	144	22	13
	<i>Hindered phenolics.</i>				
11	Butylated hydroxytoluene	228,600	176	40	17
12	Irganox 1010	154,500	175	44	15
13	Irganox 1076	190,900	175	38	16
14	Alvinox FB	105,400	177	48	17
15	Alvinox 100	155,400	178	50	15
16	Ronotec 201	112,900	157	28	14
17	Uvasorb 20H	132,100	170	29	14
18	Uvasorb MET	155,600	173	40	16
	<i>Acrylates.</i>				
19	Uvinol 3035	185,500	179	45	12
20	Uvinol 3039	118,800	173	35	14
	<i>Amines.</i>				
21	Anox ODS	189,700	177	43	31
22	Chimassorb 944	No conversion to PLA			-
23	Tinuvin 770	No conversion to PLA			-
	<i>Sulphur-based.</i>				
24	Lankromark DLTPD	157,900	174	39	17
25	Robac ZDBC	65,700	163	31	45
	<i>Peroxides.</i>				
26	Dibenzoyl peroxide	67,700	169	18	14
27	Cumylperoxide	59,200	147	10	17

[0024] Examples 28-49. Vial polymerisations of pure L-lactide were carried out at 180°C for 20 hours. The catalyst used was tin octoate at a concentration level of 50ppm with respect to the lactide monomer. Stabilisers used and addition levels (in wt%) are given in Tables 2-4. Analysis of mw, Tm, crystallinity level (%cr) and yellowness index (YI) of PLA product was carried out by standard methods and the results are given in Table 5. Product designations in Tables 2-4 are tradenames or registered trademarks.

Table 2.

Example	28	29	30	31	32	33	34	35
<i>Hindered phenolics.</i>								
Butylated hydroxytoluene	0.2	0.2	0.2	0.2	0.2	-	-	-
Irganox 1076	-	-	-	-	-	0.2	0.2	0.2
<i>Phosphorus-based.</i>								
Santicizer 148	0.1	-	-	-	-	0.1	-	-
Triphenyl phosphite	-	0.1	-	-	-	-	0.1	-
Irgafos 168	-	-	0.1	-	-	-	-	0.1
Alkanox 240	-	-	-	0.1	-	-	-	-
Alkanox P24	-	-	-	-	0.1	-	-	-

Table 3.

Example	36	37	38	39	40	41	42	43	44	45
<i>Acrylates.</i>										
Uvinol 3035	0.2	0.2	0.2	0.2	0.2	0.2	-	-	-	0.2
Uvinol 3039	-	-	-	-	-	-	0.2	0.2	0.2	-
<i>Hindered phenolics.</i>										
Irganox 1076	-	-	-	-	-	-	-	-	-	0.1
<i>Phosphorus-based.</i>										
Ethanox 398	0.1	-	-	-	-	-	-	-	-	-
Santicizer 148	-	0.1	-	-	-	-	0.1	-	-	-
Triphenyl phosphite	-	-	0.1	-	-	-	-	0.1	-	-
Irgafos 168	-	-	-	0.1	-	-	-	-	0.1	-
Alkanox 240	-	-	-	-	0.1	-	-	-	-	-
Alkanox P24	-	-	-	-	-	0.1	-	-	-	-

Table 4.

Example	46	47	48	49
<i>Acrylates.</i>				
Uvinol 3035	0.15	0.15	0.15	0.15
<i>Hindered phenolics.</i>				
Irganox 1076	0.1	0.1	0.1	0.1
<i>Phosphorus-based.</i>				
Santicizer 148	0.05	-	-	-
Irgafos 168	-	0.05	-	-
Alkanox 240	-	-	0.05	-
Alkanox P24	-	-	-	0.05

Table 5.

Example	PLA mw	PLA Tm	%cr of PLA	PLA YI
28	366,300	150	19	11

Table 5. (continued)

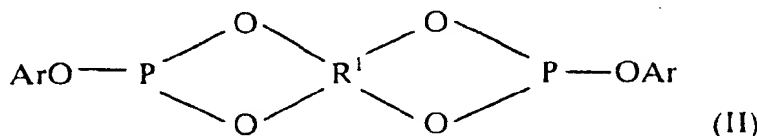
Example	PLA mw	PLA Tm	%cr of PLA	PLA YI
29	363,400	144	18	12
30	283,900	172	2	9
31	272,400	170	6	9
32	202,900	170	30	13
33	341,100	169	14	10
34	311,100	147	15	9
35	225,000	174	39	13
36	186,500	148	24	5
37	327,800	169	33	9
38	276,400	162	19	8
39	251,500	151	17	7
40	244,100	170	28	7
41	243,000	156	12	8
42	363,400	153	18	6
43	304,000	160	19	5
44	177,900	164	28	7
45	247,800	172	38	10
46	176,600	163	31	3
47	176,200	177	41	2
48	169,300	176	47	3
49	99,400	175	47	2

[0025] The stabilisers used in the Examples are manufactured or supplied by the following:

- Ciba
- Irgafos 168
 - Irganox 1010
 - Irganox 1076
 - Chimassorb 944
- Tinuvin 770
- 3v
- Alkanox P24
 - Alkanox 240
 - Alvinox FB
 - Alvinox 100
 - Uvasorb 20H
 - Uvasorb MET
- Monsanto
- Santicizer 148
- Aldrich
- Triphenylphosphite
- Lowe
- Lowinox TNPP
- Ethyl
- Ethanox 398
- ICI
- Butylated hydroxytoluene
- Roche
- Ronotec 201
- BASF
- Uvinol 3035
 - Uvinol 3039
- Great Lakes Chemicals
- Anox ODS
- Akros
- Lankromark DL TDP
- Robinson Brothers
- Robac ZDBC
- Akzo
- Dibenzoyl peroxide
 - Cumyl peroxide

Claims

1. A stabilised biodegradable polyester composition, comprising a biodegradable polyester of lactic acid and/or glycolic acid, and a stabiliser which comprises (a) a phosphite- or phosphate-containing compound and/or a hindered phenolic compound, and (b) an acrylate.
2. A composition according to claim 1, in which the polyester is obtained by polymerisation of lactide and/or glycolide.
3. A composition according to claim 1 or 2, in which the stabiliser comprises a phosphite- or phosphate-containing compound and an acrylate.
4. A composition according to claim 1 or 2, in which the stabiliser composition comprises a phosphite- or phosphate-containing compound, a hindered phenolic compound and an acrylate.
5. A composition according to any of claims 1 to 4, in which the phosphite- or phosphate-containing compound is of the general formula (I), (II) or (III):



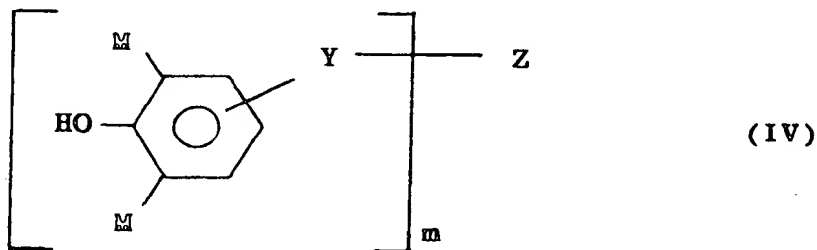
in which

x is 0 or 1;

Ar each independently is an optionally substituted aromatic group; and

R¹ and R² are aliphatic or aromatic groups.

6. A composition according to any of claims 1 to 5, in which the hindered phenolic compound is of the general formula (IV):



where

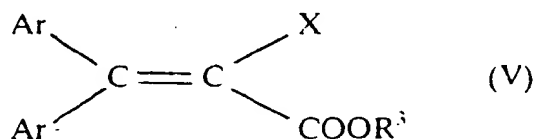
M each independently is an aliphatic group;

Y is an aliphatic group;

m is an integer from 1 to 4; and

Z is an aliphatic or aromatic group or
H if m is 1.

7. A composition according to any of claims 1 to 6, in which the acrylate is of the general formula (V):



where

Ar each independently is an optionally substituted aromatic group;
R³ is an aliphatic group; and
X is an electron-withdrawing group.

8. A composition according to any of claims 1 to 7, in which the total content of stabiliser is up to 2 wt%, preferably from 0.1 to 0.5 wt%, of the weight of biodegradable polyester.
9. Use of a stabiliser composition comprising (a) a phosphite- or phosphate-containing compound and/or a hindered phenolic compound, and (b) an acrylate, for stabilising a biodegradable polyester of lactic acid and/or glycolic acid.
10. A process for preparing a stabilised polyester composition, which comprises polymerisation of lactide and/or glycolide in the presence of a stabiliser comprising (a) a phosphite- or phosphate-containing compound and/or a hindered phenolic compound, and (b) an acrylate.
11. A shaped product prepared from a stabilised biodegradable polyester composition according to any of claims 1 to 8.



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EUROPEAN SEARCH REPORT

Application Number
EP 99 30 0874

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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A,P	EP 0 882 751 A (KK KOBE) 9 December 1998 * examples 15,18 *	1,2	
A	EP 0 677 561 A (MITSUI TOATSU) 18 October 1995 * page 5, line 41 - line 42 * * page 6, line 23 *	1-3	
A	EP 0 587 069 A (MITSUI TOATSU) 16 March 1994 * examples 1-7 *	1,4	
A	GB 1 124 870 A (SHELL) * page 1, line 51 - line 52 * * page 2, line 110 - line 125 *	1,2	
			TECHNICAL FIELDS SEARCHED (Int.Cl.8)
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The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 8 June 1999	Examiner Engel, S
<p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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